WIRELESS AND MOBILE NETWORK (Assignment –I)

Submitted in partial fulfilment of the requirements for the degree of

Master of Technology in Information Technology

by

Vijayananda D Mohire

(Enrolment No.921DMTE0113)

Information Technology Department
Karnataka State Open University
Manasagangotri, Mysore – 570006
Karnataka, India
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WIRELESS AND MOBILE NETWORK

CERTIFICATE

This is to certify that the Assignment-I entitled WIRELESS AND MOBILE NETWORK, subject code: MT31C submitted by Vijayananda D Mohire having Roll Number 921DMTE0113 for the partial fulfilment of the requirements of Master of Technology in Information Technology degree of Karnataka State Open University, Mysore, embodies the bonafide work done by him under my supervision.

Place: ________________

Signature of the Internal Supervisor

Date: ________________

Name

Designation

Preface

This document has been prepared specially for the assignments of M.Tech – IT III Semester. It is mainly intended for evaluation of assignment of the academic M.Tech – IT, III semester. I have made a sincere attempt to gather and study the best answers to the assignment questions and have attempted the responses to the questions. I am confident that the evaluators will find this submission informative and evaluate based on the furnished details.

For clarity and ease of use there is a Table of contents and Evaluators section to make easier navigation. Evaluators are welcome to provide the necessary comments against each response; suitable space has been provided at the end of each response.

I am grateful to Infysys academy, Koramangala, Bangalore in making this a big success. Many thanks for the timely help and attention in making this possible within specified timeframe. Special thanks to Mr. Vivek and Mr. Prakash for their timely help and guidance.

Candidate's Name and Signature   Date

Table of Contents

Table of Figures

WIRELESS AND MOBILE NETWORK

RESPONSE TO ASSIGNMENT - I

Question 1 State mobile communication principles. What are Digital Systems?

Answer 1

Mobile Communications Principles

Each mobile uses a separate, temporary radio channel to talk to the cell site. The cell site talks to many mobiles at once, using one channel per mobile. Channels use a pair of frequencies for communication one frequency (the forward link) for transmitting from the cell site and one frequency (the reverse link) for the cell site to receive calls from the users. Radio energy dissipates over distance, so mobiles must stay near the base station to maintain communications. The basic structure of mobile networks includes telephone systems and radio services. Where mobile radio service operates in a closed network and has no access to the telephone system, mobile telephone service allows interconnection to the telephone network.

Early Mobile Telephone System Architecture

Traditional mobile service was structured in a fashion similar to television broadcasting: One very powerful transmitter located at the highest spot in an area would broadcast in a radius of up to 50 kilometres. The cellular concept structured the mobile telephone network in a different way. Instead of using one powerful transmitter, many low-power transmitters were placed throughout a coverage area. For example, by dividing a metropolitan region into one hundred different areas (cells) with low-power transmitters using 12 conversations (channels) each, the system capacity theoretically could be increased from 12 conversations or voice channels using one powerful transmitter to 1,200 conversations (channels) using one hundred low-power transmitters.

Mobile Telephone System Using the Cellular Concept

Interference problems caused by mobile units using the same channel in adjacent areas proved that all channels could not be reused in every cell. Areas had to be skipped before the same channel could be reused. Even though this affected the efficiency of the original concept, frequency reuse was still a viable solution to the problems of mobile telephony systems.

Engineers discovered that the interference effects were not due to the distance between areas, but to the ratio of the distance between areas to the transmitter power (radius) of the areas. By reducing the radius of an area by 50 percent, service providers could increase the number of potential customers in an area fourfold. Systems based on areas with a one-kilometer radius would have one hundred times more channels than systems with areas 10 kilometers in radius. Speculation led to the conclusion that by reducing the radius of areas to a few hundred meters, millions of calls could be served.

The cellular concept employs variable low-power levels, which allow cells to be sized according to the subscriber density and demand of a given area. As the population grows, cells can be added to accommodate that growth. Frequencies used in one cell cluster can be reused in other cells. Conversations can be handed off from cell to cell to maintain constant phone service as the user moves between cells.

The cellular radio equipment (base station) can communicate with mobiles as long as they are within range. Radio energy dissipates over distance, so the mobiles must be within the operating range of the base station. Like the early mobile radio system, the base station communicates with mobiles via a channel. The channel is made of two frequencies, one for transmitting to the base station and one to receive information from the base station.

Cellular System Architecture

Increases in demand and the poor quality of existing service led mobile service providers to research ways to improve the quality of service and to support more users in their systems. Because the amount of frequency spectrum available for mobile cellular use was limited, efficient use of the required frequencies was needed for mobile cellular coverage. In modern cellular telephony, rural and urban regions are divided into areas according to specific provisioning guidelines. Deployment parameters, such as amount of cell-splitting and cell sizes, are determined by engineers experienced in cellular system architecture.

Provisioning for each region is planned according to an engineering plan that includes cells, clusters, frequency reuse, and handovers.

Cells

A cell is the basic geographic unit of a cellular system. The term cellular comes from the honeycomb shape of the areas into which a coverage region is divided. Cells are base stations transmitting over small geographic areas that are represented as hexagons. Each cell size varies depending on the landscape. Because of constraints imposed by natural terrain and man-made structures, the true shape of cells is not a perfect hexagon.

Clusters

A cluster is a group of cells. No channels are reused within a cluster. Figure 1 illustrates a seven-cell cluster.

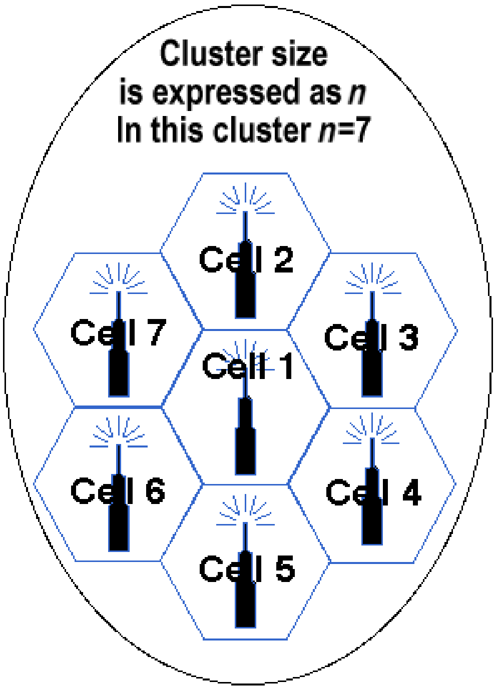

Figure 1 Clusters

Frequency Reuse

Because only a small number of radio channel frequencies were available for mobile systems, engineers had to find a way to reuse radio channels to carry more than one conversation at a time. The solution the industry adopted was called frequency planning or frequency reuse. Frequency reuse was implemented by restructuring the mobile telephone system architecture into the cellular concept.

The concept of frequency reuse is based on assigning to each cell a group of radio channels used within a small geographic area. Cells are assigned a group of channels that is completely different from neighbouring cells. The coverage area of cells is called the footprint. This footprint is limited by a boundary so that the same group of channels can be used in different cells that are far enough away from each other so that their frequencies do not interfere.

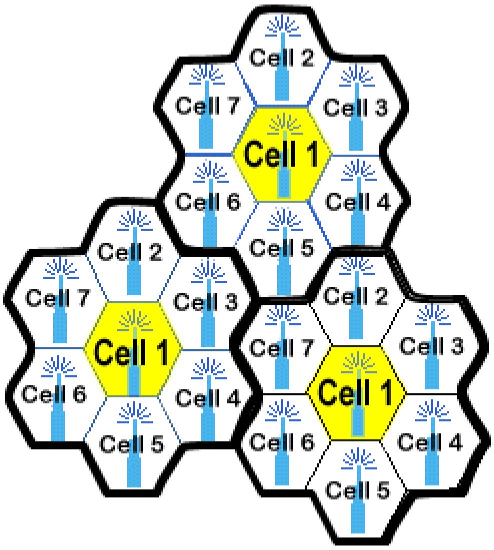

Figure 2 Frequency Reuse

Cells with the same number have the same set of frequencies. Here, because the number of available frequencies is 7, the frequency reuse factor is 1/7. That is, each cell is using 1/7 of available cellular channels.

Cell Splitting

Unfortunately, economic considerations made the concept of creating full systems with many small areas impractical. To overcome this difficulty, system operators developed the idea of cell splitting. As a service area becomes full of users, this approach is used to split a single area into smaller ones. In this way, urban centres can be split into as many areas as necessary to provide acceptable service levels in heavy-traffic regions, while larger, less expensive cells can be used to cover remote rural regions.

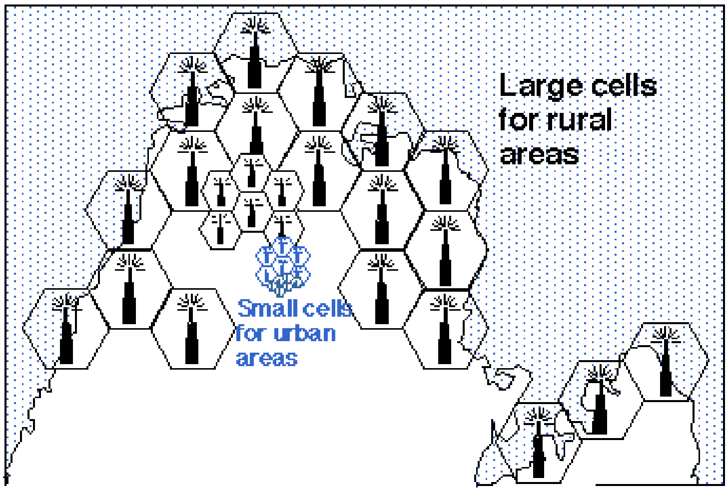

Figure 3 Cell Splitting

Handoff

The final obstacle in the development of the cellular network involved the problem created when a mobile subscriber travelled from one cell to another during a call. As adjacent areas do not use the same radio channels, a call must either be dropped or transferred from one radio channel to another when a user crosses the line between adjacent cells. Because dropping the call is unacceptable, the process of handoff was created. Handoff occurs when the mobile telephone network automatically transfers a call from radio channel to radio channel as mobile crosses adjacent cells.

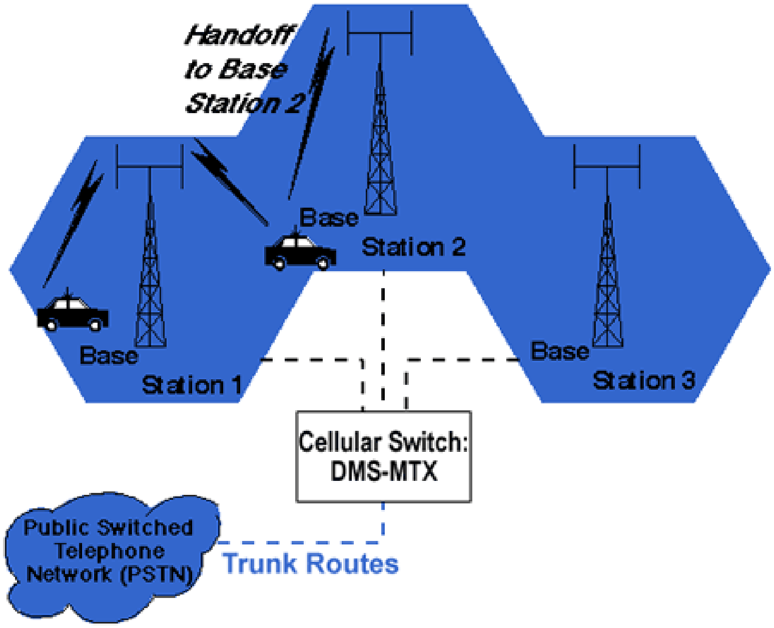

Figure 4 Handoff

During a call, two parties are on one voice channel. When the mobile unit moves out of the coverage area of a given cell site, the reception becomes weak. At this point, the cell site in use requests a handoff. The system switches the call to a stronger-frequency channel in a new site without interrupting the call or alerting the user. The call continues as long as the user is talking, and the user does not notice the handoff at all.

Cellular System Components

The cellular system offers mobile and portable telephone stations the same service provided fixed stations over conventional wired loops. It has the capacity to serve tens of thousands of subscribers in a major metropolitan area. The cellular communications system consists of the following six major components that work together to provide mobile service to subscribers.

1. Mobile subscriber unit (MSU) or Mobile station (MS)
2. Air Interface standard
3. Base station (BS)

4. Databases
5. Security Mechanism
6. Gateway consisting of MTSO or MSC

Mobile Subscriber Units (MSUs) or Mobile station (MS)

The mobile subscriber unit consists of a control unit and a transceiver that transmits and receives radio transmissions to and from a cell site and an antenna system. Whenever a mobile unit wants to setup a call, it contacts the cell site of the particular cell in which it exists at that time. The cell site consists of control unit, antennas, power plant and data terminals. The cell site is in fact acting as an interface to the MTSO. After the mobile unit contacts the cell site, the cell site in turn contacts the MTSO which processes the call further depending on whether it is a mobile to mobile call or mobile to fixed station call.

For example, in GSM networks, the mobile station will consist of the Mobile equipment (ME) and the SIM card.

Air Interface standard

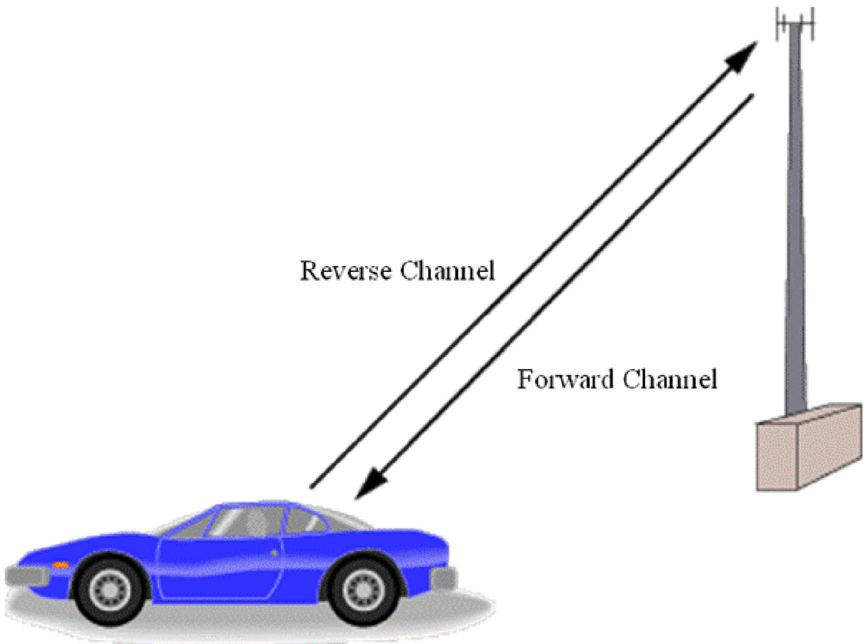

Figure 5 Air Interface

- ❖ Common Air Interface: A Standard that defines Communication between a Base Station and Mobile
    - ❖ Specifies Four Channels [Voice Channels and Control / Setup Channels]

- **FVC:** Forward Voice Channel
- **RVC:** Reverse Voice Channel
- **FCC:** Forward Control Channel
- **RCC:** Reverse Control Channel

There are three main air interface protocols or standards: frequency division multiple access (FDMA), time division multiple access (TDMA) and code division multiple access (CDMA). These standards are basically the medium access (MAC) protocols that define the rules for entities to access the communication medium.

Base station (BS)

A base station is a fixed station in a mobile cellular system used for radio communications with mobile units. They consist of radio channels and transmitter and receiver antenna mounted on a tower.

Databases

Another integral component of a cellular system is the databases. Databases are used to keep track of information like billing, caller location, subscriber data etc. There are two main databases called Home Location Register (HLR) and Visitor Location Register (VLR). The HLR contains the information of each subscriber who resides in the same city as the mobile switching center (MSC). The VLR temporarily stores the information for each visiting subscriber in the coverage area of the MSC. Thus, the VLR is the database that supports roaming capability.

Security Mechanism

The security mechanism is to confirm that a particular subscriber is allowed to access the network and also to authenticate the billing.

There are two databases used for security mechanism: Equipment Identity Register (EIR) and Authentication Center (AuC). The EIR identifies stolen or fraudulently altered phones that transmit identity data that does not match with information in either the HLR or VLR. The AuC, on the other hand, manages the actual encryption and verification of each subscriber.

Gateway

The final basic component of a cellular system is the Gateway. The gateway is the communication links between two wireless systems or between wireless and wired systems. There are two logical components inside the gateway: Mobile switching centre (MSC) and interworking function (IWF)

The Mobile telephone Switching Office (MTSO) is the central office for mobile switching that hosts the Gateway and other equipments. It houses the mobile switching centre (MSC), field monitoring, and relay stations for switching calls from cell sites to wire line central offices (PSTN). In analog cellular networks, the MSC controls the system operation. The MSC controls calls, tracks billing information, and locates cellular subscribers. It contains the EIR database.

The IWF connects the cellular base stations and the mobile stations to Internet and perform protocol translation if needed.

Digital Systems

Many digital cellular systems have been developed. A few of them are given below:

i) TDMA (Time Division Multiple Access)

ii) GSM (Global System for Mobile)

iii) PCS (Personal Communication Services)

iv) CDMA (Code Division Multiple Access)

These systems have their own merits and demerits such as one being better than the other in terms of speech quality achieved at the expense of system complexity

Digital technology offers the opportunity for improved transmission in cellular systems. This is due to powerful error detection and recovery techniques, which can be used to counter the debilitating effects of noise, fading and interference. Digital technology also provides the basis for security in the forms of encryption and authentication. Finally, digital technology requires less in the way of mobile transmit power, which increases battery life in portable mobile units.

Digital cellular technologies also offer the promise of effective data transmission via cellular services. Although their vocoders prohibit the use of conventional modems, recent extensions to standards provide low-throughput data traffic in either a circuit-switched mode or via a digital control channel.

Packet –switched data services are also being developed by the proponents of digital cellular standards. As demand for mobile telephone service has increased, service providers found that basic engineering assumptions borrowed from wireline (landline) networks did not hold true in mobile systems. While the average landline phone call lasts at least 10 minutes, mobile calls usually run 90 seconds. Engineers who expected to assign 50 or more mobile phones to the same radio channel found that by doing so they increased the probability that a user would not get dial tone –this is known as call-blocking probability. As a consequence, the early systems quickly became saturated, and the quality of service decreased rapidly. The critical problem was capacity. The general characteristics of time division multiple access (TDMA), Global system for Mobile Communications (GSM), Personal Communications Service (PCS) 1900, and code division multiple access(CDMA) promise to significantly increase the efficiency of cellular telephone systems to allow a greater number of simultaneous conversations.

As demand for mobile telephone service has increased, service providers found that basic engineering assumptions borrowed from wire line (landline) networks did not hold true in mobile systems. While the average landline phone call lasts at least 10 minutes, mobile calls usually run 90 seconds. Engineers who expected to assign 50 or more mobile phones to the same radio channel found that by doing so they increased the probability that a user would not get dial tone this is known as call-blocking probability. As a consequence, the early systems quickly became saturated, and the quality of service decreased rapidly. The critical problem was capacity. The general characteristics of time division multiple access (TDMA), Global System for Mobile Communications (GSM), personal communications service (PCS) 1900, and code division multiple access (CDMA) promise to significantly increase the efficiency of cellular telephone systems to allow a greater number of simultaneous conversations. Figure 6 shows the components of a typical digital cellular system.

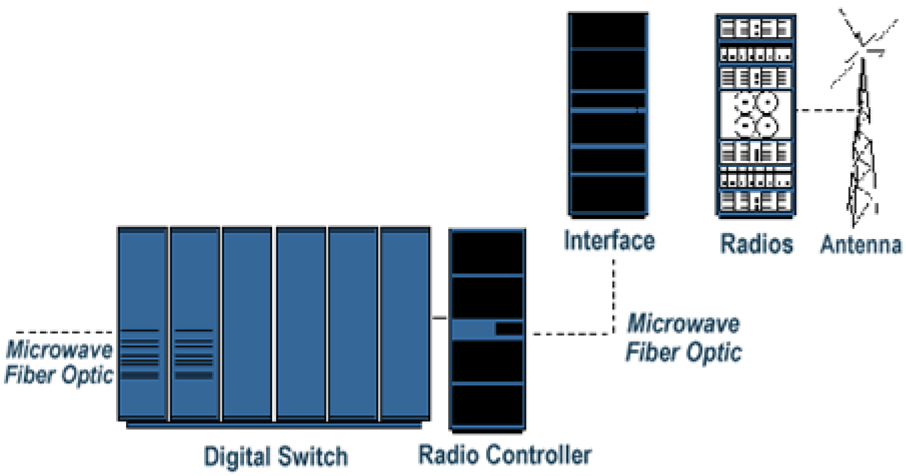

Figure 6 Typical digital cellular system

The advantages of digital cellular technologies over analog cellular networks include increased capacity and security. Technology options such as TDMA and CDMA offer more channels in the same analog cellular bandwidth and encrypted voice and data. Because of the enormous amount of money that service providers have invested in AMPS hardware and software, providers look for a migration from AMPS to digital analog mobile phone service (DAMPS) by overlaying their existing networks with TDMA architectures.

Table 1 AMPS/ DAMPS comparison

Parameter	Analog (AMPS)	Digital (DAMPS)
Standard	EIA-553 (AMPS)	IS-54 (TDMA + AMPS)
Spectrum	824 MHz to 891 MHz	824 MHz to 891 MHz
Channel bandwidth	30 KHz	30 KHz
Channels	21 CC/395 VC	21 CC/395 VC
Conversations per channel	1	3 to 6
Subscriber capacity	40 to 50 conversations per cell	125 to 300 conversations per cell
TX/ RCV type	Continuous	Time shared bursts
Carrier type	Constant phase variable frequency	Constant frequency variable phase
Mobile/ Base relationship	Mobile slaved to base	Authority shared cooperatively
Privacy	Poor	High
Noise immunity	Poor	High
Fraud detection	ESN plus optional password(PIN)	ESN plus optional passed(PIN)

1) Time Division Multiple Access (TDMA)

North American digital cellular (NADC) is called DAMPS which used TDMA. Because AMPS preceded digital cellular systems, DAMPS uses the same setup protocols as analog AMPS. TDMA has the following characteristics:

- IS-54 standard specifies traffic on digital voice channels
- Initial implementation triples the calling capacity of AMPS systems
- Capacity improvements of 6 to 15 times that of AMPS are possible
- Many blocks of spectrum in 800 MHz and 1900 MHz are used
- All transmissions are digital

TDMA is one of several technologies used in wireless communications. TDMA provides each call with time slots, Figure 7, so that several calls can occupy one bandwidth. Each caller is assigned a specific time slot. In some cellular systems, digital packets of information are sent during each time slot and reassembled by the receiving equipment into the original voice components. TDMA uses the same frequency band and channel allocations as AMPS. Like AMPS, TDMA provides three to six time channels in the same bandwidth as a single AMPS channel. Unlike AMPS, digital systems have the means to compress the spectrum used to transmit voice information by compressing idle time and redundancy of normal speech. TDMA is the digital standard and has 30-kHz bandwidth. Using digital voice encoders, TDMA is able to use up to six channels in the same bandwidth where AMPS uses one channel.

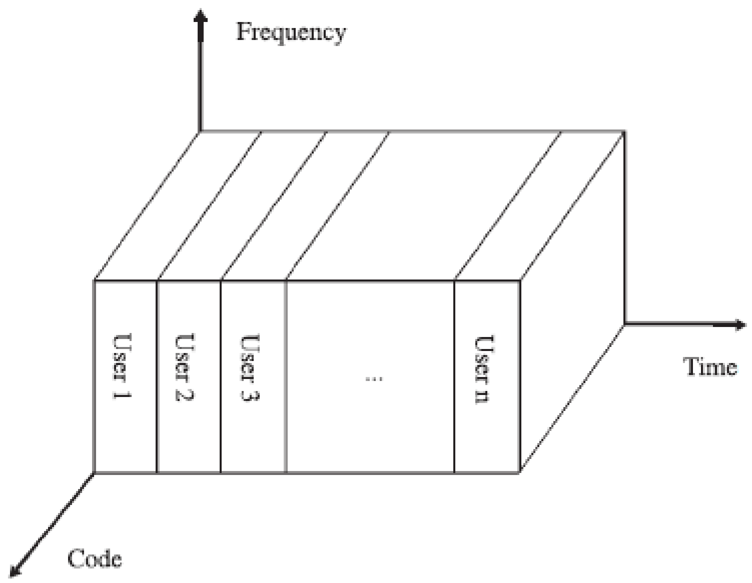

Figure 7 TDMA(Time Division Multiple access)

In DAMPS, which use the same 30-kHz channel as AMPS, 159 bits (along with overhead bits for a total of 260 bits) can be transmitted in two of six time slots in a frame. At 25 frames per second, DAMPS has three times the capacity of AMPS using the same number of channels. TDMA can operate in either the 800-MHz cellular spectrum (IS-54/D-AMPS; EIA/TIA, 1990) or the 1900-MHz PCS spectrum (IS-136; EIA/TIA, 1995).

2) Global System for Mobile (GSM)

Before the Global System for Mobile Communications (GSM) was developed, the countries of Europe used a number of incompatible first-generation cellular phone technologies. GSM was developed to provide a common second-generation technology for Europe so that the same subscriber units could be used throughout the continent. The technology has been extremely successful and is probably the most popular standard, worldwide, for new implementations. GSM first appeared in 1990 in Europe. Similar systems have now been implemented in North and South America, Asia, North Africa, the Middle East, and Australia. The GSM Association claimed over a billion subscribers worldwide by early 2004, the bulk of these in Europe and Asia Pacific, but with growing market share in North and South America.

Figure 8 shows the key functional elements in the GSM system. The boundaries at Um, Abis, and A refer to interfaces between functional elements that are standardized in the GSM documents. Thus, it is possible to buy equipment from different vendors with the expectation that they will successfully interoperate. Additional interfaces are also defined in the GSM standards, but need not concern us here.

Mobile Station (MS) A mobile station communicates across the Um interface, also known as the **air interface,** with a base station transceiver in the same cell in which the mobile unit is located. The **mobile equipment** (ME) refers to the physical terminal, such as a telephone or PCS (personal communications service) device, which includes the radio transceiver, digital signal processors, and the **subscriber identity module** (SIM). The SIM is a portable device in the form of a smart card or plug-in module that stores the subscriber's identification number, the networks the subscriber is

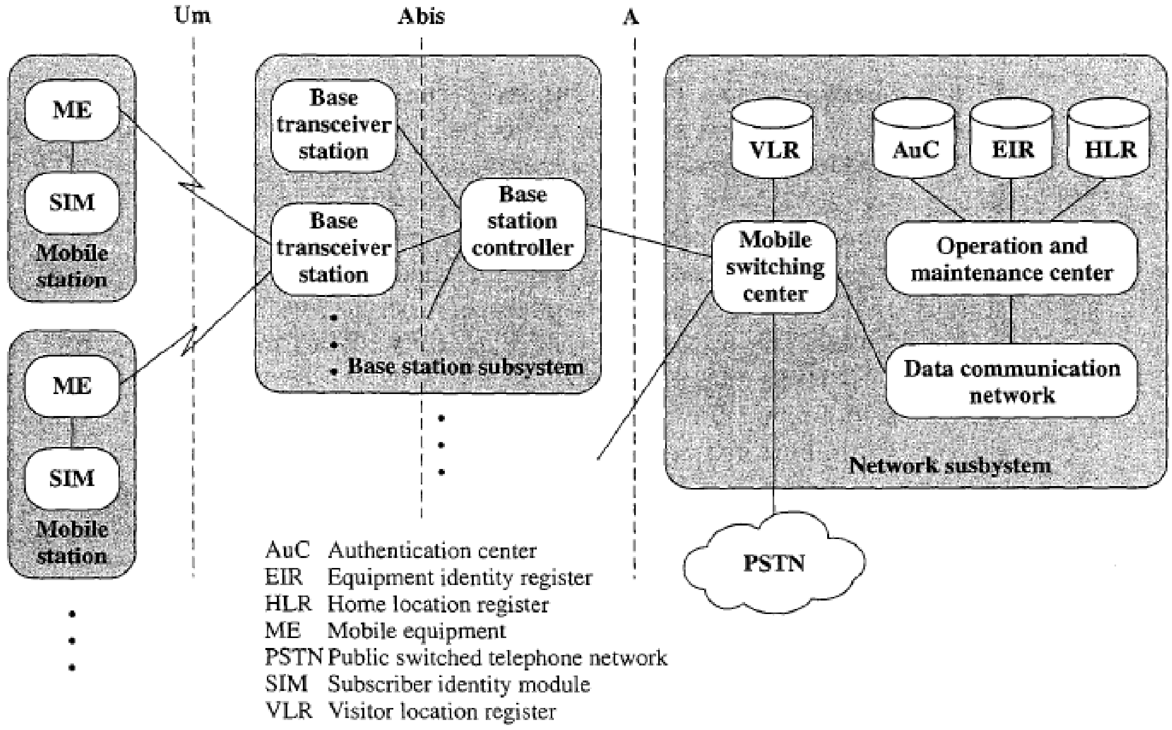

Figure 8 Overall GSM Architecture

authorized to use, encryption keys, and other information specific to the subscriber. The GSM subscriber units are totally generic until an SIM is inserted. Therefore, a subscriber need only carry his or her SIM to use a wide variety of subscriber devices in many countries simply by inserting the SIM in the device to be used. In fact, except for certain emergency communications, the subscriber units will not work without a SIM inserted.

Base Station Subsystem A base station subsystem (BSS) consists of a base station controller and one or more base transceiver stations. Each **base transceiver station** (BTS) defines a single cell; it includes a radio antenna, a radio transceiver, and a link to a base station controller. A GSM cell can have a radius of between 100 m and 35 km, depending on the environment. A **base station controller** (BSC) may be collocated with a BTS or may control multiple BTS units and hence multiple cells. The BSC reserves radio frequencies, manages the handoff of a mobile unit from one cell to another within the BSS, and controls paging.

Network Subsystem The network subsystem (NS) provides the link between the cellular network and the public switched telecommunications networks. The NS controls handoffs between cells in different BSSs, authenticates users and validates their accounts, and includes functions for enabling worldwide roaming of mobile users. The central element of the NS is the **mobile switching center** (MSC). It is supported by four databases that it controls:

- **Home location register (HLR) database:** The HLR stores information, both permanent and temporary, about each of the subscribers that "belongs" to it (i.e., for which the subscriber has its telephone number associated with the switching center).
- **Visitor location register (VLR) database:** One important, temporary piece of information is the location of the subscriber. The location is determined by the VLR into which the subscriber is entered. The visitor location register maintains information about subscribers that are currently physically in the region covered by the switching center. It records whether or not the subscriber is active and other parameters associated with the subscriber. For a call coming to the subscriber, the system uses the telephone number associated with the subscriber to identify the home switching center of the subscriber. This switching center can find in its HLR the switching center in which the subscriber is currently physically located. For a call coming from the subscriber, the VLR is used to initiate the call. Even if the subscriber is in the area covered by its home switching center, it is also represented in the switching center's VLR, for consistency.
- **Authentication center database (AuC):** This database is used for authentication activities of the system; for example, it holds the authentication and encryption keys for all the subscribers in both the home and visitor location registers. The center controls access to user data as well as being used for authentication when a subscriber joins a network. GSM transmission is encrypted, so it is private. A stream cipher, A5, is used to encrypt the transmission from subscriber to base transceiver. However, the conversation is in the clear in the landline network. Another cipher, A3, is used for authentication.

- **Equipment identity register database (EIR):** The EIR keeps track of the type of equipment that exists at the mobile station. It also plays a role in security (e.g., blocking calls from stolen mobile stations and preventing use of the network by stations that have not been approved).

The Operation and Support System (OSS) The operations and maintenance center (OMC) is connected to all equipment in the switching system and to the BSC through MSC. The implementation of the OMC is called the operation and support system (OSS). The OSS is the functional entity from which the network operator monitors and controls the system. The purpose of OSS is to offer the customer cost-effective support for centralized, regional and local operational and maintenance activities that are required for a GSM network. An important function of OSS is to provide a network overview and support the maintenance activities of different operation and maintenance organizations.

3) Personal Communication Services (PCS)

The future of telecommunications includes PCS. PCS at 1900 MHz (PCS 1900) is the North American implementation of digital cellular system (DCS) 1800 (GSM). Trial networks were operational in the United States by 1993, and in 1994 the Federal Communications Commission (FCC) began spectrum auctions. As of 1995, the FCC auctioned commercial licenses. In the PCS frequency spectrum, the operator's authorized frequency block contains a definite number of channels. The frequency plan assigns specific channels to specific cells, following a reuse pattern that restarts with each nth cell. The uplink and downlink bands are paired mirror images. As with AMPS, a channel number implies one uplink and one downlink frequency (e.g., Channel 512 = 1850.2-MHz uplink paired with 1930.2-MHz downlink).

Personal Communication Services is a system, very similar to Cellular Phone Service with great emphasis on **personal services** (such as Paging, Caller ID, and E-mail] and mobility. Originated in UK, to improve its competitiveness in the field. PCS has smaller cell size, therefore, requires more infra-structure. PCS works in 1.85-1.99 GHz band. PCS uses TDMA Technology but with 200 KHz Channel Bandwidth with eight time-slots (as compared to 30 KHz and 3 time-slots used by Digital Cellular Phone System IS-54/IS-136). GSM and Cellular Digital Packet Data (CDPD) also use PCS Technology.

4) Code Division Multiple Access (CDMA)

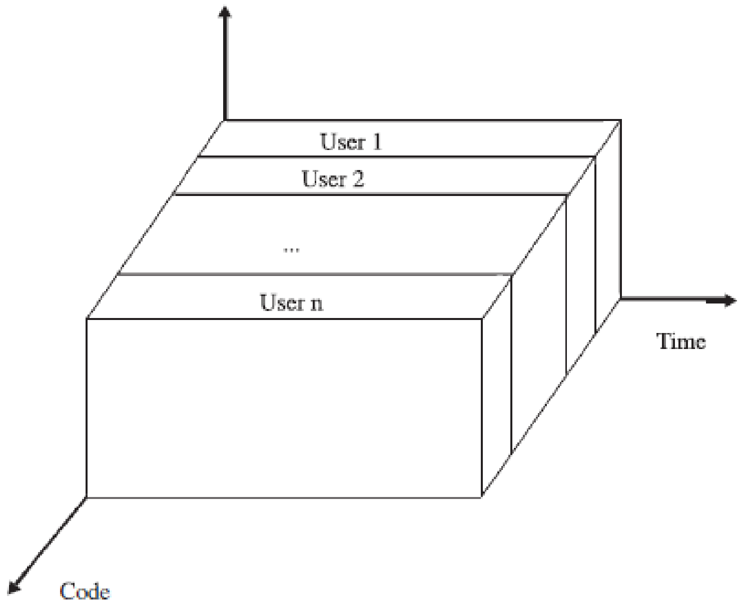

Figure 9 CDMA(Code Division Multiple access)

CDMA takes an entirely different approach from TDMA. In CDMA, multiple MSs share the same wideband of spectrum. Instead of being assigned to time slots as in TDMA, each MS is assigned a unique sequence code. Each MS's signal is spread over the entire bandwidth by the unique sequence code. At the receiver, that same unique code is used to recover the signal. Although the radio spectrum is shared, no interference can arise because the sequence codes used by the sharing MSs are basically orthogonal. Figure 9 illustrates the concept of CDMA.

CDMA is a digital air interface standard, claiming 8 to 15 times the capacity of analog. It employs a commercial adaptation of military, spread-spectrum, single-sideband technology. Based on spread spectrum theory, it is essentially the same as wireline service; the primary difference is that access to the local exchange carrier (LEC) is provided via wireless phone. Because users are isolated by code, they can share the same carrier frequency, eliminating the frequency reuse problem encountered in AMPS and DAMPS. Every CDMA cell site can use the same 1.25-MHz band, so with respect to number of clusters it is always one. This greatly simplifies frequency planning in a fully CDMA environment.

CDMA is an interference-limited system. Unlike AMPS/TDMA, CDMA has a soft capacity limit; however, each user is a noise source on the shared channel and the noise contributed by users accumulates. This creates a practical limit to how many users a system will sustain. Mobiles that transmit excessive power increase interference to other mobiles. For CDMA, precise power control of mobiles is critical in maximizing the system's capacity and increasing battery life of the mobiles. The goal is to keep each mobile at the absolute minimum power level that is necessary to ensure acceptable service quality. Ideally, the power received at the base station from each mobile should be the same (minimum signal to interference).

Advantages:

1. Increased Capacity
2. Simplified frequency reuse
3. Reduced Multipathing concerns
4. Soft Hand-off
5. Variable rate speech coding
6. Increased security
7. Increases Mobile Unit Battery Life

Evaluator's Comments if any:

Question 2 Explain OFDM for Mobile Communications

Answer 2

Over the past few years, there has been increasing emphasis on extending the services available on wired public telecommunications networks to mobile/movable nonwired telecommunications users. At present, in addition to voice services, only low-bit-rate data services are available to mobile users. However, demands for wireless broadband multimedia communication systems (WBMCS) are anticipated within both the public and private sectors. Wired networks cannot support extension to wireless mobile networks because mobile radio channels are more contaminated than wired data-transmission channels. It also cannot preserve the high QoS required in wired networks.

The mobile radio channel is characterized by multipath reception: the signal offered to the receiver contains not only a direct line-of-sight (LOS) radio wave, but also a large number of reflected radio waves that arrive at the receiver at different times. Delayed signals are the result of reflections from terrain features such as trees, hills, mountains, vehicles, or buildings. These reflected, delayed waves interfere with the direct wave and cause intersymbol interference (ISI), which in turn causes significant degradation of network performance. A wireless network should be designed to minimize adverse effects.

To create broadband multimedia mobile communication systems, it is necessary to use high-bit-rate transmission of at least several megabits per second. However, if digital data is transmitted at the rate of several megabits per second, the delay time of the delayed waves is greater than 1 symbol time. Using adaptive equalization techniques at the receiver is one method for equalizing these signals. There are practical difficulties in operating this equalization at several megabits per second with compact, low-cost hardware.

To overcome such a multipath-fading environment with low complexity and to achieve the desired results, an overview of the orthogonal frequency division multiplexing (OFDM) transmission scheme is mentioned below. OFDM is one of the applications of a parallel-data-transmission scheme, which reduces the influence of multipath fading and makes complex equalizers unnecessary.

Orthogonal Frequency Division Multiplexing (OFDM) is special form of multi-carrier modulation, patented in 1970. It is particularly suited for transmission over a dispersive channel.

In a multipath channel, most conventional modulation techniques are sensitive to intersymbol interference unless the channel symbol rate is small compared to the delay spread of the channel.

OFDM is significantly less sensitive to intersymbol interference than conventional modulation such as BPSK or QAM, because a special set of signals is used to build the composite transmitted signal. The basic idea is that each bit occupies a frequency-time window which ensures little or no distortion of the waveform. In practice, it means that bits are transmitted in parallel over a number of frequency-nonselective channels.

OFDM represents a different system-design approach. It can be thought of as a combination of modulation and multiple-access schemes that segments a communications channel in such a way that many users can share it. Whereas TDMA segments are according to time and CDMA segments are according to spreading codes, OFDM segments are according to frequency. It is a technique that divides the spectrum into a number of equally spaced tones and carries a portion of a user's information on each tone. A tone can be thought of as a frequency, much in the same way that each key on a piano represents a unique frequency. OFDM can be viewed as a form of frequency division multiplexing (FDM), however has an important special property that each tone is orthogonal with each other tone. FDM typically requires there to be frequency guard bands between the frequencies so that they do not interfere with each other. OFDM allows the spectrum of each tone to overlap, and because they are orthogonal, they do not interfere with each other. By allowing the tones to overlap, the overall amount of spectrum required is reduced.

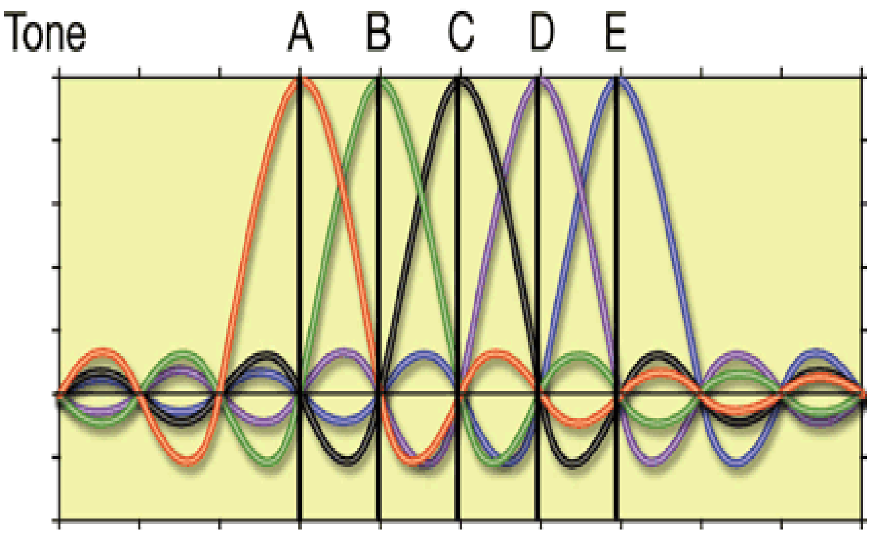

Figure 10 OFDM Tones

The fundamental principle of the OFDM system is to decompose the high rate data stream (bandwidth = W) into N lower rate data streams and then to transmit them simultaneously over a large number of subcarriers. A sufficiently high value of N makes the individual bandwidth (W/N) of subcarriers narrower than the coherence bandwidth (Bc) of the channel. The individual subcarriers as such experience flat fading only, and this can be compensated using a trivial frequency domain single- tap equalizer. The choice of individual subcarrier is such that they are orthogonal to each other, which allows for the overlapping of subcarriers because the orthogonality ensures the separation of subcarriers at the receiver end. This approach results in a better spectral efficiency than that of FDMA systems, where no spectral overlap of carriers is allowed.

The spectral efficiency of an OFDM system is shown pictorially in Figure 11, which illustrates the difference between the conventional nonoverlapping multicarrier technique (such as FDMA) and the overlapping multicarrier modulation technique [such as discrete multitone (DMT), OFDM, and the like]. As shown in Figure 11, the overlapping multicarrier modulation technique can achieve superior bandwidth utilization. To realize the benefits of the overlapping

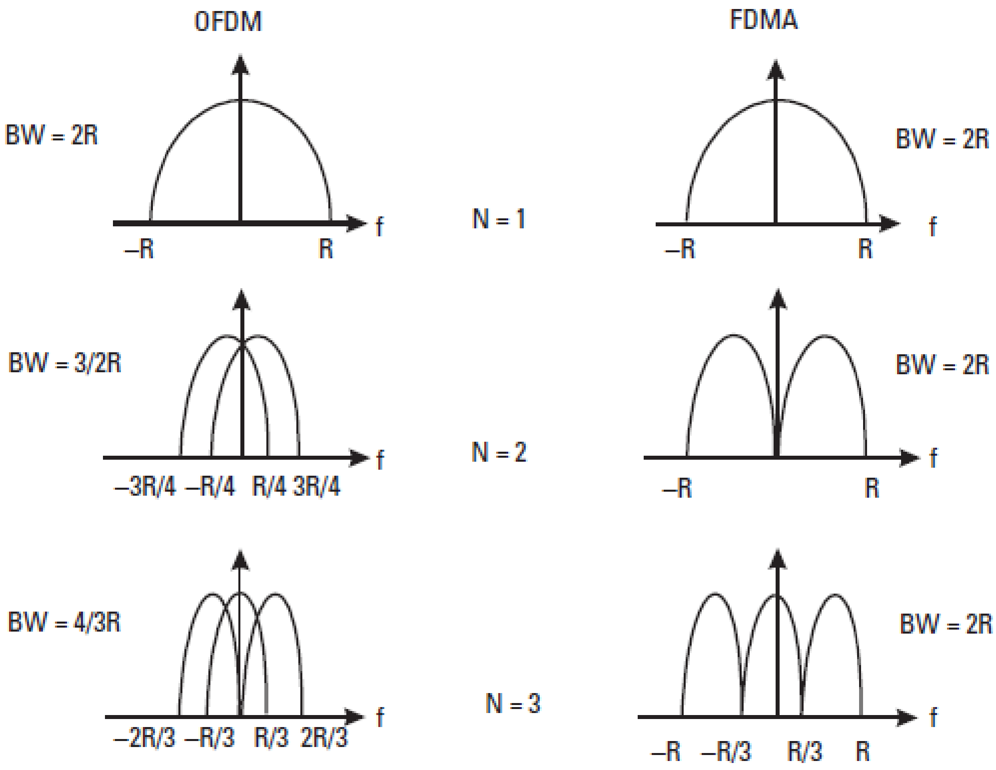

Figure 11 Orthogonal multicarrier versus conventional multicarrier

multicarrier scheme, however, requires reduction of cross talk between subcarriers, which translates into preserving orthogonality among the modulated subcarriers.

The word orthogonal dictates a precise mathematical relationship between frequencies of subcarriers in the OFDM-based system. In a normal frequency division multiplex system, many carriers are spaced apart in such a way that the signals can be received using conventional filters and demodulators. In such receivers, guard bands are introduced between the different carriers in the frequency domain, which results in a reduction of the spectrum efficiency. It is possible, however, to arrange the carriers in an OFDM system such that the sidebands of the individual subcarriers overlap and the signals are still received without adjacent carrier interference. The OFDM receiver can be constructed as a bank of demodulators, translating each subcarrier down to dc and then integrating over a symbol period to recover the transmitted data. If all subcarriers down convert to frequencies that, in the time domain, have a whole number of cycles in a symbol period T, then the integration process results in zero Inter carrier Interference (ICI). These subcarriers can be made linearly independent (i.e., orthogonal) if the carrier spacing is a multiple of 1/T, which will be proved later to be the case for OFDM-based systems.

OFDM is a modulation technique in that it enables user data to be modulated onto the tones. The information is modulated onto a tone by adjusting the tone's phase, amplitude or both. In the most basic form, a tone may be present or disabled to indicate a one or zero bit of information; however either phase shift keying (PSK) or Quadrature amplitude modulation (QAM) is typically employed. An OFDM system takes a data stream and splits it into N parallel data streams, each at a rate 1/N of the original rate. Each stream is then mapped to a tone at a unique frequency and combined together using the inverse fast fourier (IFFT) to yield the time-domain waveform to be transmitted.

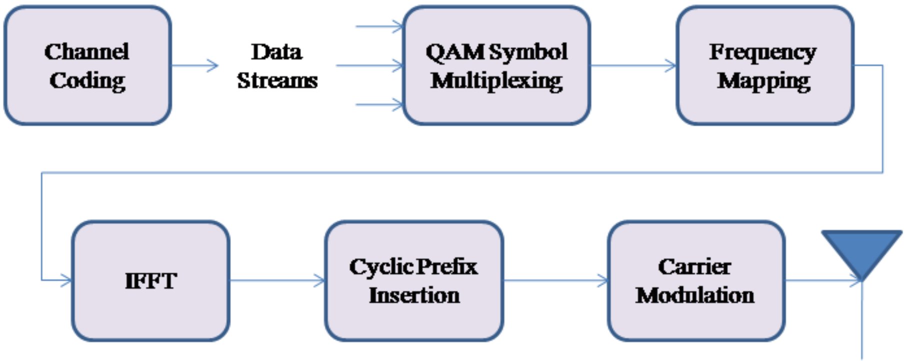

Figure 12 OFDM transmitter chain

For example, if a 100-tone system were used, a single data stream with a rate of 1 Mbps would be converted into 100 streams of 10 Kbps. By creating slower parallel data streams, the bandwidth of the modulation symbol is effectively decreased by a factor of 100, or equivalently, the duration of the modulation symbol is increased by a factor of 100. Proper selection of system parameters, such as the number of tones and tone spacing, can greatly reduce, or even eliminate, ISI, because typical multipath delay spread represents a much smaller proportion of the lengthened symbol time. Viewed another way, the coherence bandwidth of the channel can be much smaller, because the symbol bandwidth has been reduced. The need for complex multi-tap time-domain equalizers can be eliminated as a result.

OFDM can also be considered as a multi-access technique, because an individual tone or groups of tones can be assigned to different users. Multiple users share a given bandwidth in this manner, yielding the system called OFDMA. Each user can be assigned a predetermined number of tones when they have information to send, or alternatively, a user can be assigned a variable number of tones based on the amount of information that they have to send. The assignments are controlled by the media access control (MAC) layer, which schedules the resource assignments based on users demand.

OFDM can be combined with frequency hopping to create a spread spectrum system, realizing the benefits of frequency diversity and interference averaging previously described for CDMA. In a frequency hopping spread spectrum system, each user's set of tones is changed after each time period (usually corresponding to a modulation symbol). By switching frequencies after each symbol time, the losses due to frequency selective fading are minimized. Although frequency hopping and CDMA are different forms of spread spectrum, they achieve comparable performance in a multipath fading environment and provide similar interference averaging benefits.

OFDM therefore provides the best of the benefits of TDMA in that users are orthogonal to one another, and CDMA, as previously mentioned, while avoiding the limitations of each, including the need for TDMA frequency planning and equalization, and multiple access interference in the case of CDMA.

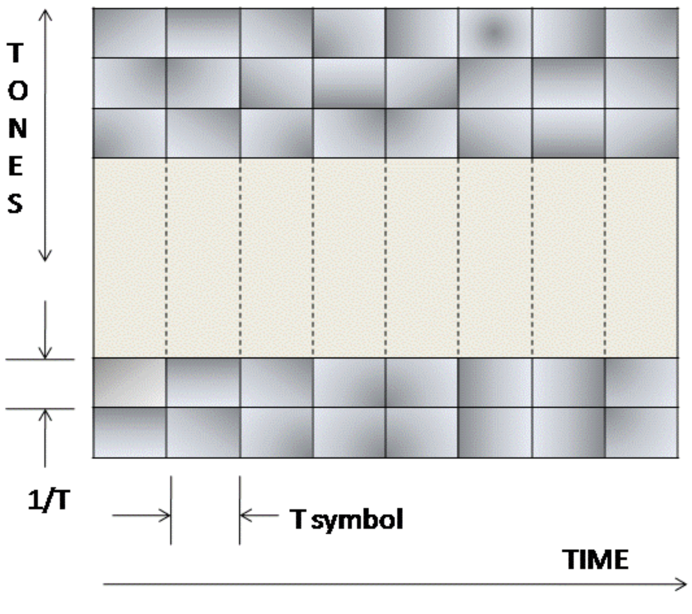

Figure 13 Two-dimensional illustration of OFDM channel resource

The OFDM transmission scheme has the following key advantages:

1. OFDM is an efficient way to deal with multipath; for a given delay spread, the implementation complexity is significantly lower than that of a single-carrier system with an equalizer.
2. In relatively slow time-varying channels, it is possible to enhance capacity significantly by adapting the data rate per SC according to the signal-to-noise ratio (SNR) of that particular SC.
3. OFDM is robust against narrowband interference because such

interference affects only a small percentage of the SCs.

4. OFDM makes single-frequency networks possible, which is especially attractive for broadcasting applications.

On the other hand, OFDM also has some drawbacks compared with single carrier modulation:

1. OFDM is more sensitive to frequency offset and phase noise.
2. OFDM has a relatively large peak-to-average-power ratio, which tends to reduce the power efficiency of the radio frequency (RF) amplifier.

OFDM Applications:

In the 1960s, the OFDM technique was used in several high-frequency military systems such as KINEPLEX, ANDEFT, and KATHRYN. For example, the variable-rate data modem in KATHRYN was built for the high-frequency band. It used up to 34 parallel low-rate phase-modulated channels with a spacing of 82 Hz.

In the 1980s, OFDM was studied for high-speed modems, digital mobile communications, and high-density recording. One of the systems realized the OFDM techniques for multiplexed quadrature amplitude modulation (QAM) using DFT; also, by using pilot tone, stabilizing carrier and clock frequency control and trellis coding could also be implemented. Moreover, various-speed modems were developed for telephone networks.

In the 1990s, OFDM was exploited for wideband data communications over mobile radio FM channels, high-bit-rate digital subscriber lines (HDSL; 1.6 Mbps), asymmetric digital subscriber lines (ADSL; up to 6 Mbps), very-high-speed digital subscriber lines (VDSL; 100 Mbps), digital audio broadcasting (DAB), and high definition television (HDTV) terrestrial broadcasting.

OFDM has been the accepted standard for digital TV broadcasting for more than a decade. European DAB and DVB-T standards use OFDM. HIPERLAN-2 standard is also using OFDM techniques and so is the 5 GHz extension of IEEE 802.11 standard. More recently, IEEE 802.16 has standardized OFDM for both Fixed and Mobile WiMAX.

Evaluator's Comments if any: